DOCUMENT RESUME

ED 254 407 SE 045 420

AUTHOR Stuessy, Carol L.
TITLE A Causal Model for the Development of Scientific Reasoning in Adolescents.
PUB DATE Apr 85
NOTE 18p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (58th, French Lick Springs, IN, April 15-18, 1985).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Abstract Reasoning; Adolescents; Age; Cognitive Processes; *Field Dependence Independence; Intelligence Quotient; *Locus of Control; *Logical Thinking; *Predictor Variables; Science Education; Secondary Education; *Secondary School Science; Sex; *Student Characteristics; Student Experience
IDENTIFIERS Science Education Research

ABSTRACT

A model for the development of scientific reasoning in adolescents was formulated largely upon the basis of Piagetian theory. Included as potential determinants of scientific reasoning were: experience; age; locus of control; field dependence-independence (FID); rigidity/flexibility; intelligence quotient (IQ); and sex. Causal relationships between these variables were hypothesized a priori with strong theoretical, heuristic, and empirical support. Data (obtained from 106 middle school students and 92 high school students) were used to test the hypothesized model by path analysis. Multiple regressions were performed according to path analytic methods to acquire standardized beta weights for each of the hypothesized paths. These beta values were used as path coefficients for each of the posited relationships. Significant coefficients were obtained for these variables and scientific reasoning: age; IQ; FID; and experience. Age and IQ were stronger determinants of scientific reasoning that were FID and experience. An indirect effect of locus of control on scientific reasoning through the FID variable was also supported. None of the paths involving sex or rigidity/flexibility was significant. The revised model (which excluded sex and rigidity/flexibility) included significant paths which explained 61 percent of the variance in scientific reasoning. Implications for science instruction are addressed. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED254407

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
✓ This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

A CAUSAL MODEL FOR THE DEVELOPMENT OF SCIENTIFIC REASONING IN ADOLESCENTS

Carol L. Stuessy
Worthington City Schools
Worthington, OH 43085

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Carol L. Stuessy
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Introduction

A model of human functioning based upon exploration and self-actualization was adopted for this research. This model conceptualizes man as an active, open, curious, growing biological system (Dewey, 1916; Maslow, 1962; Piaget, 1972; Mooney, 1980). Rationality is theorized to be adaptively significant and to develop naturally as a function of unrestricted human experiencing with the passage of time. Rationality, in effect, frees man to experience fully the realities of himself, his actions, and his ideas in a constantly changing, very complex environment. Ordered, systematic, abstract thought enables man to experience, reflect upon, and generalize beyond the specific events in his environment, to expand his frame of reference and thus allow for a stable, consistent way of perceiving the world and himself within it. Scientific thought is incorporated within this model to be a precise extension of the self-actualizing human being's rationality. Bronowski (1951) and Cohen (1953) support the notion that scientific thought is adaptive and characteristically human--that it enables the active restructuring of human experience and therefore the prediction of future events. Science is perceived as a process of prediction which is conscious and rational (as

SE 045 420

opposed to intuitive), and rational prediction is a major contributor to the success of the human species in adaptation to the environment (Bronowski, 1951).

Piagetian theory also provides for the natural development of scientific thought processes within the course of human development. A number of "factors" were identified by Piaget as contributing to the development of higher level thinking schemata. These included Experience, Social Transmission, Maturation, Aptitude, and Equilibration (Piaget, 1972). Piaget suggested that this final factor determines the rhythm by which the other factors interact and ultimately affect cognitive development. The highest level of cognitive development (i.e., Piaget's "formal operational stage") is comprised of a number of higher level mental schemata (Inhelder and Piaget, 1958) which include those identified in the present research as "scientific reasoning abilities."

Problem

The development of reasoning abilities via the primary and secondary school science classroom has long been a major goal of the science education community. With this goal in mind, numerous interventions have been suggested and implemented for the enhancement and/or development of higher-level cognitive abilities in children from the early primary years throughout the post-secondary educational experience. Unfortunately, much of the research has indicated an ineffectiveness of science instruction strategies in the attainment of higher-level cognitive abilities for children of any age, including those who have completed high school and continued their education in college. It has been suggested by Welch (1980) that a lack of attention to personological variables in children may have interfered with the measured

success of strategies aimed at developing reasoning abilities. Although personological variables have been identified often in educational research as correlates of higher-level thinking abilities, empirical evidence is scarce which indicates causality between these variables and the development of scientific reasoning abilities. This study aimed to develop and test a causal model for the development of scientific reasoning abilities which included a number of posited relationships involving personological variables as potential direct and indirect determinants of scientific reasoning. These results might then be used in support of particular interventions in the science classroom to enhance the development of scientific reasoning abilities in adolescents.

Method

Subjects

The community from which the subjects were chosen for this study was an upper middle-class, predominantly white suburb of Columbus, Ohio. A heterogeneously grouped middle school interdisciplinary team (n=106) of seventh graders comprised the younger group of subjects examined. The sample of older adolescents was drawn from five high school classes (two general chemistry classes, a general humanities class, and two English classes) containing students from tenth, eleventh, and twelfth grades (n=92).

Instruments

The emphasis of the present research was on the development of rational thinking skills involved in scientific methodology, the hypothetico-deductive mental processes identified herein as "scientific reasoning" abilities. More specifically, these abilities were defined to include those consistent,

logical thought patterns which are employed during the process of scientific inquiry which enable individuals to propose relationships between observed phenomena, to design experiments which test hypotheses concerning the proposed relationships, to determine all possible alternatives and outcomes, to consider probabilities of occurrences, to predict logical consequences, to weigh evidence or proof, and to use a number of instances to justify a particular conclusion. Possession by adolescents of these scientific reasoning abilities was determined by performance on a Scientific Reasoning Test. The individual abilities examined with this instrument were combinatorial, proportional, and probabilistic reasoning; and the isolation and control of variables. This test included 13 items from Lawson's Test of Formal Operations (Lawson, 1978) and two items written by the researcher.

Other instruments were developed or chosen to measure factors discussed by Piaget which contribute to the acquisition of formal operational mental schemata in adolescents (Piaget, 1972). The Cognitive and Recreational Activity Scale was developed by the author to evaluate the experiential component of cognitive development. Included within this measure were a number of activities identified by a panel of experts as most probably affecting the development of scientific reasoning abilities in adolescents. Rationales were developed for the application of two constructs, locus of control and rigidity/flexibility, to the Piagetian variables of social transmission and equilibration, respectively. A locus of control measure, the Intellectual Achievement Responsibility Questionnaire (Crandall, Katkovsky, and Crandall, 1965), was used as the variable for social transmission. For the rigidity/flexibility measure, Breskin's Rigidity Test (Breskin, 1968), was employed. Aptitude variables examined included an IQ test (Short Form of Academic Aptitude, 1970), a measure of field dependence-independence

(Concealed Figures Test; Thurstone and Jeffrey, 1956), and gender. Age was also a variable. Table 1 lists the variables examined in the research with their corresponding constructs and instruments. The causal model depicting the interactive effects among these variables appears as Figure 1, where lines and directions of arrows reflect the nature of the hypothesized relationships between variables (Asher, 1976).

Procedure

For all classes, the instruments and a background data sheet were administered on two consecutive days. The day before actual testing, the students were presented with an oral description of the study, and they received a consent form and a letter explaining the nature of the study. All students agreed to participate in the study. The consent form and explanatory letter were taken home and signed by a parent or guardian. The day of testing, consent forms were collected and packets which contained coded copies of answer sheets to all instruments were distributed to students. Students wrote their names on the outside of the packets, and they were requested to provide information regarding their age, gender, and grade in school on a demographic sheet within the folder. This sheet was also used by the researcher for recording the IQ score found in the student's permanent school record. After IQ scores were recorded, folders with the students' names were discarded to insure student anonymity.

The Scientific Reasoning Test was administered as a group demonstration test, in which students watched a demonstration performed by the researcher. At the end of the demonstration, a question was posed to the students about what they had observed. The students were then required to choose an answer from a set of four choices written on the answer sheet. They also wrote a

TABLE 1

VARIABLES EXAMINED IN THE RESEARCH WITH THEIR CORRESPONDING CONSTRUCTS AND INSTRUMENTS

VARIABLE	CONSTRUCT	INSTRUMENT
Experiential Variable*		Cognitive and Recreational Activity Scale (CRAS)
Social Transmission*	Locus of Control	Intellectual Achievement Responsibility Questionnaire (IAR)
Maturation*		Age
Aptitude*	Field Dependence-Independence Independence	Concealed Figures Test (CFT)
Equilibration*	Rigidity/ Flexibility	Breskin's Rigidity Test (BRT)
IQ	Ability to learn	Short Form Test of Academic Aptitude (SFTAA)
Gender		
Scientific Reasoning Ability		Scientific Reasoning Test (SRT)

* Those variables marked with asterisks are ones which were identified by Piaget as affecting the development of formal operational thought.

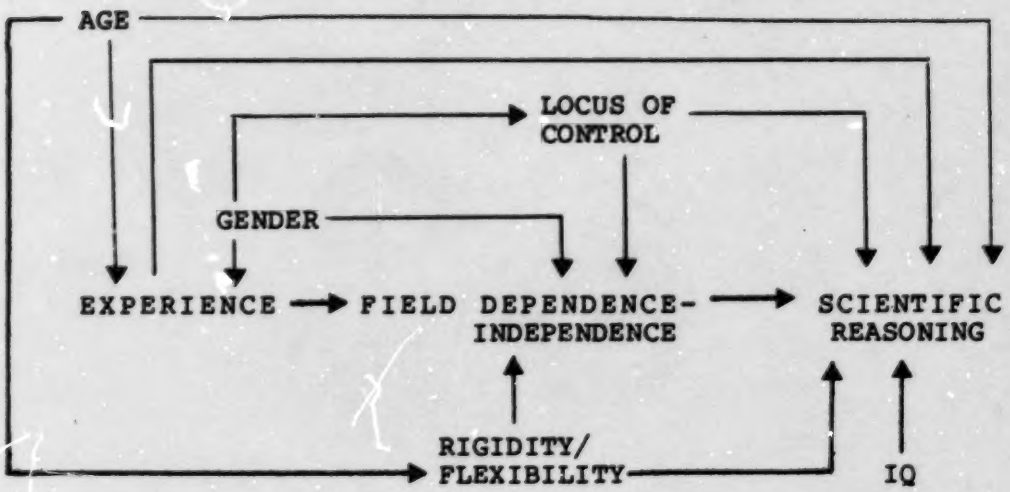

Figure 1. A causal model displaying hypothesized relationships between variables which ultimately affect scientific reasoning ability in adolescents.

justification for their choice in their own words following the choice of the response. All 15 items of the test were graded by the researcher on the basis of whether the correct response was supported by an appropriate justification. After the administration of the Scientific Reasoning Test, other instruments were administered and the demographic data sheets were filled out. IQ scores were obtained by the researcher from the students' permanent school records.

Data were entered onto magnetic tape. All instruments except the Scientific Reasoning Test were graded by computer. Statistical analyses of data were performed using SPSS Programs PEARSON CORR and REGRESSION (Nie, Hull, Jenkins, Steinbrenner, and Bent, 1975) in order to obtain simple coefficients of correlation and estimates of path coefficients. To obtain path coefficients, each endogenous variable in the model was regressed by the variables which directly impinged upon it. The standardized regression coefficient, beta, was used as the estimated path coefficient. Table 2 summarizes the results of the regressions from which the original path coefficients were obtained. On the basis of the level of significance obtained for the beta weights, the model was "trimmed," as discussed by Pedhazur (1982). Path coefficients with levels of significance greater than 0.05 were eliminated from the final model. As well, the path from Age to Rigidity/Flexibility was eliminated, as there were no subsequent paths from the Rigidity/Flexibility variable which impinged directly or indirectly upon the ultimate dependent variable of interest, scientific reasoning. The simplified, trimmed model was then subjected to final analysis in which the remaining paths were tested using simple and multiple regression techniques as described earlier.

TABLE 2

SUMMARY OF REGRESSIONS FROM WHICH ORIGINAL PATH COEFFICIENTS WERE OBTAINED FOR TESTING THE CAUSAL MODEL OF SCIENTIFIC REASONING

Path	From	To	Beta	p
P84	Experience	Scientific Reasoning	0.11	<0.02*
P74	Experience	Field Dep-Ind	0.11	0.78
P85	Locus	Scientific Reasoning	0.05	0.34
P75	Locus	Field Dep-Ind	0.28	<0.01*
P41	Age	Experience	-0.01	0.93
P61	Age	Rigid/Flex	-0.32	<0.01*
P81	Age	Scientific Reasoning	0.53	<0.01*
P87	Field Dep-Ind	Scientific Reasoning	0.14	0.02*
P76	Rigid/Flex	Field Dep-Ind	-0.12	0.11
P86	Rigid/Flex	Scientific Reasoning	-0.02	0.65
P83	IQ	Scientific Reasoning	0.49	<0.01*
P52	Gender	Locus of Control	0.09	0.29
P42	Gender	Experience	-0.08	0.34
P72	Gender	Field Dep-Ind	0.02	0.78

*Indicates statistical significance at alpha <= 0.05

Results and Discussion

Figure 2 displays the final model, which includes only variables for which there were statistically significant path coefficients. Significant ($p < 0.05$) path coefficients were obtained for these variables and Scientific Reasoning: Age, IQ, Field Dependence-Independence, and Experience. Age and IQ (with path coefficients of 0.54 and 0.49, respectively) were stronger determinants of Scientific Reasoning than were Field Dependence-Independence (0.15) and Experience (0.11). An indirect effect of Locus of Control on Scientific Reasoning through the Field Dependence-Independence variable was also supported, with an obtained path coefficients of 0.28 between Locus of Control and Field Dependence-Independence. None of the paths involving Gender or leading from Rigidity/Flexibility were statistically significant, and these two variables were eliminated from the revised model. Table 3 summarizes the results of the multiple and simple regressions performed in the final analysis. Inclusion of these variables explained 61 percent of the variance in Scientific Reasoning.

Table 4 compares the results of simple correlations made between pairs of variables in the model and the estimated changes in variance which occurs with the addition of the final variable in multiple regression techniques. This comparison attests to the value of causal modeling in determining the nature of hypothesized relationships between variables in the study. The simple pairwise correlations (r^2 values) indicate the strengths of individual variables in independently predicting scientific reasoning, as well as indicating the variance shared between the two variables. Reduction in the predictive strength of these variables is evident when the results of the multiple regressions (Δr^r) are observed. A comparison of the two values (r^2 and Δr^2) estimating shared

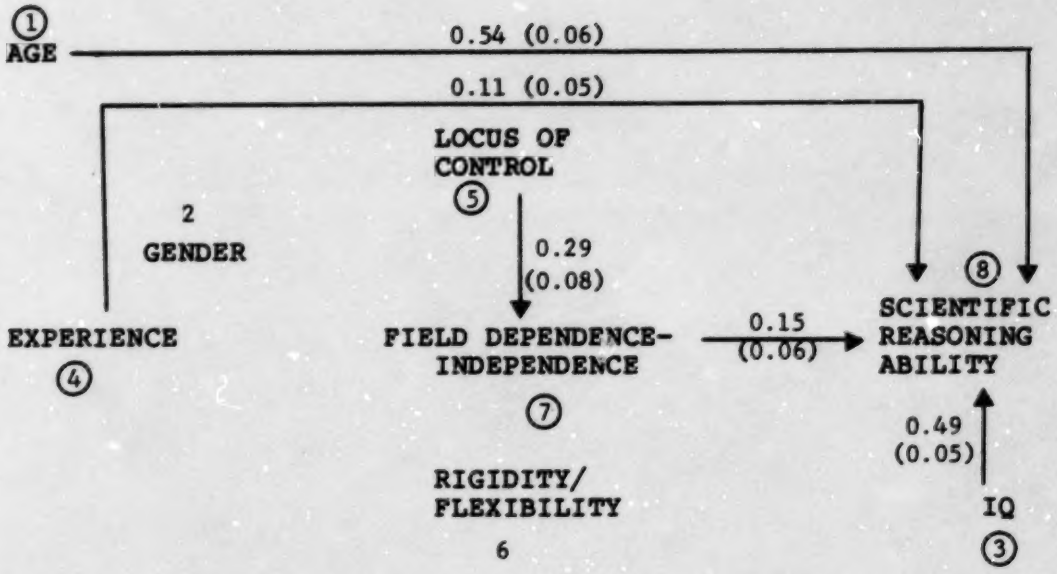

Figure 2. The final revised causal model displaying significant ($p < 0.05$) relationships between variables shown to have direct and/or indirect effects on Scientific Reasoning. The path coefficients appearing in this model are the standardized beta weights obtained in regressions performed during the testing of this model.

TABLE 3

SUMMARY OF REGRESSIONS FROM WHICH REVISED PATH COEFFICIENTS WERE OBTAINED FOR THE SIMPLIFIED CAUSAL MODEL FOR SCIENTIFIC REASONING

Path	From	To	Beta	p
P84	Experience	Scientific Reasoning	0.11	0.02
P81	Age	Scientific Reasoning	0.54	<0.01
P83	IQ	Scientific Reasoning	0.49	<0.01
P87	Field Dep-Ind	Scientific Reasoning	0.15	<0.01
P75	Locus	Field Dep-Ind	0.29	<0.01

TABLE 4

SIMPLE AND MULTIPLE SQUARED COEFFICIENTS OF CORRELATION FOR PATHS IN THE REVISED MODEL FOR SCIENTIFIC REASONING

	Shared Variance	
Path	(r^2)	(ΔR^2)
Age to Scientific Reasoning	0.32	0.24
IQ to Scientific Reasoning	0.23	0.21
FDI to Scientific Reasoning	0.26	0.01
Experience to Scientific Reasoning	<0.01[a]	0.01
Locus of Control to FDI	0.04	0.08

[a]All values from which shared variance was calculated were significant at p <= 0.004 except this one.

variance indicates that the shared variance, as implied by the simple r^2, is overestimated, as that variance represents variance shared with other variables as well. The Δr^2 value represents shared variance between the two variables in question after the variance shared with other variables has been removed by multiple regression.

The value of causal modeling is also seen in interpreting the causal nature of the relationships between variables. Correlational data can not be used to imply causality between variables. Path analysis, however, allows for causal relationships to be hypothesized on the basis of theoretical and prior research considerations which are made prior to statistical analysis. In path analysis, scientific reasoning abilities in adolescents are therefore predicted from a number of interrelated variables from which the contamination of shared variance has been removed; and causal relationships are suggested which underly the observed differences in scientific reasoning abilities in students exhibiting variability in a number of personological variables. Although this study was not experimental in nature, the model testing procedures of path analysis enabled the exploration of a number of variables proposed to be in causal relationship with one another, as well as with scientific reasoning.

Implications for Teaching Science

While future research is needed to clarify and extend these findings, results of this study indicate tentative implications for the teaching of science in elementary and secondary school. The results of this research imply that the implementation and/or modification of some particular educational strategies may lead to the development of scientific reasoning abilities in adolescents. That Experience and Locus of Control were found to affect Scientific Reasoning suggests that direct manipulation of these variables may enhance the development of scientific reasoning abilities in adolescents. Suggested are choices of science experiences which involve students in direct manipulation of objects and in activities which require mental reformulations of experience into three-dimensional space, such as the mental activities involved in model-building and sewing from patterns (see Inhelder and Piaget, 1958). The classroom setting should allow for children to feel in control of and accountable for their own rewards, rather than from external sources (Rowe, 1974). That IQ and Field Dependence-Independence were shown to have direct effects on scientific reasoning abilities suggests individualizing instruction to meet the needs of children exhibiting differences in aptitudes and abilities which normally occur in the heterogeneously grouped classroom (see Karplus,1979; and Witkin, Moore, Goodenough, and Cox, 1977). The indirect effect of Locus of Control upon Field Dependence-Independence suggests that experiences which encourage a shift from external towards internal locus of control (Kahle, 1983; Rowe, 1974) should also affect the observed level of field independence of an individual. According to the results of this study, this effect should then be realized further in the enhancement of scientific reasoning abilities. As well, further research is suggested by these results to examine the nature of the

pathway involving the Locus, Field Dependence-Independence, and Scientific Reasoning variables.

Finally, this study has shown that reasoning abilities increase with the age of students. This is not a surprising finding, but instead reinforces the science teacher's expectations that improvement in scientific reasoning may take years to be accomplished. This study indicates that the acquisition of scientific reasoning abilities is a complex developmental process determined by a number of inter-related elements internal and external to adolescents, and that teaching for the development of scientific reasoning abilities may require attention not only to a number of classroom details but also to the adoption of generalized curriculum goals within the entire span of the elementary-secondary school science experience.

Literature Cited

Asher, H.B. Causal Modeling. Sage University Paper series on Quantitative Applications in the Social Sciences, 07-100. Beverly Hills, CA: Sage Publications, 1976.

Breskin, S. Measurement of rigidity, a non-verbal test. Perceptual and Motor Skills, 1976, 27, 1203-1206.

Bronowski, J. The Common Sense of Science. New York: Vintage Books, 1951.

Cohen, M.R. Reason and Nature. An Essay on the Meaning of Scientific Method. Glencoe, IL: The Free Press Publishers, 1953.

Crandall, V.C., Katkovsky, W., and Crandall, V.J. Children's beliefs in their control of reinforcement in intellectual academic achievement behaviors. Child Development, 1965, 36, 91-109.

Dewey, J. Democracy and Education: An Introduction to the Philosophy of Education. New York: The MacMillan Co., 1916.

Inhelder, B., and Piaget, J. The Growth of Logical Thinking from Childhood to Adolescence. (A. Parsons and S. Milgram, Trans.). New York: Basic Books, Inc., 1958.

Kahle, J.B. The disadvantaged majority: science education for women. AETS Outstanding Paper for 1983. Burlington, NC: Carolina Biological Supply Co., 1983.

Karplus, R. Teaching for the development of reasoning. In A.E. Lawson (Ed.), The Psychology of Teaching for Thinking and Creativity. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1979.

Lawson, A.E. The development and validation of a classroom test of formal reasoning. Journal of Research in Science Teaching, 1978, 15, 11-24.

Maslow, A.H. Toward A Psychology of Being. Princeton, NJ: D. Van Nostrand Co., 1962.

Mooney, R.L. Research Papers: The Phenomenon of Mind, Vol. II of a Series of Volumes. Selected Writings. Mimeo. Columbus, OH: The Ohio State University, 1979.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., and Bent, D.H. Statistics Package for the Social Sciences (2nd ed.). St. Louis, MO: McGraw-Hill, 1975.

Pedhazur, E.J. Multiple Regression in Behavioral Research: Explanation and Prediction (2nd ed.). Chicago: Holt, Rinehart and Winston, 1982.

Piaget, J. Intellectual evolution from adolescence to adulthood. Human Development, 1972, 15, 1-12.

Rowe, M.B. Relation of wait-time and rewards to the development of language, logic, and fate control: Part II--rewards. Journal of Research in Science Teaching, 1974, 11, 291-308.

Short Form Test of Academic Aptitude (Examiner's Manual). Monterrey, CA: CTB/McGraw-Hill, 1970.

Thurstone, L.L., and Jeffrey, T.E. Closure Flexibility (Concealed Figures, Form A). Chicago: Industrial Relations Center, 1956.

Welch, W.W. Inquiry in school science. In N.C. Harms and R.E. Yager (Eds.). What Research Says to the Science Teacher (Vol. 3). Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1980.

Witkin, H.A., Moore, C.A., Goodenough, D.R., and Cox, P.W. Field-dependent and field-independent cognitive styles and their educational implications. Review of Educational Research, 1977, 47, 1-64.